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STRESS-CORROSION CRACKING OF HIGH-STRENGTH STAINLESS STEELS IN ATMOSPHERIC ENVIRONMENTS

DEFENSE METALS INFORMATION CENTER
Battelle Memorial institute
Columbus 1, Ohio

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by

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to

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STRESS-CORROSION CRACKING OF HIGH-STRENGTH STAINLESS STEELS IN ATMOSPHERIC ENVIRONMENTS

SUMMARY

The application of high-strength steels in the construction of aircraft and missiles has created a further demand for information on the stress-corrosion properties of such steels. Several experimental programs designed to develop such data have been in progress for the last few years. In this report, the available information on the stress-corrosion cracking of the high-strength stainless steels has been assembled and tabulated according to alloy type and to the environments to which they were exposed. The stainless steels, for which some data are available, include the cold-rolled austenitics, the martensitic grades, the martensitic precipitation-hardenable grades, and the semiaustenitic precipitation hardenable grades. Exposures were in the marine atmosphere at Kure Beach, outdoors at several semiindustrial locations, and in several laboratory test environments. Data on the chemical analyses, heat treatments, and mechanical properties of the test materials are included.

All of the data compiled in this report were obtained on bent-beam specimens stressed below the yield point.

Many factors are known to influence the stress-corrosion cracking of metals. These include composition of the alloy, heat treatment, metallurgical structure, preparation of the test specimens, stress levels, and the environmental conditions. Insufficient data have been accumulated to permit quantitative comparisons of the alloys discussed in this report, and much of the information is considered preliminary because the tests are still in progress; however, tentative conclusions can be made about the utilization of these steels. The compiled data also indicate where additional testing and refinements in the procedures are needed to get more reproducible and reliable results.

Cold-worked and stress-relieved austenitic stainless steels such as AISI 301 have shown excellent resistance to stress-corrosion cracking in both marine and laboratory-type exposures. This is true on specimens stressed to over 200,000 psi. The good performance is attributed to the fact that high strength is developed by mechanical working, rather than by heat treatments.

In the 17-7 PH and PH 15-7 Mo tests also, the most resistant specimens were those in the CH 900 condition; that is, the cold-rolled and tempered structure. These alloys in the other conditions were shown to be

susceptible to stress-corrosion cracking in a marine atmosphere when stressed to over 50 per cent of the yield strength. However, susceptibility was not related solely to the strength of the alloy but was also determined by the heat treatment used to develop the properties. In general, the heat treatments that developed the strongest alloys also resulted in greater susceptibility to stress-corrosion cracking. For both alloys, in certain cases, there were large differences in exposure times between those specimens that failed and those that did not fail. No failures were reported on these alloys (17-7 PH and PH 15-7 Mo) exposed to semiindustrial atmospheres.

The data for AM 350 and AM 355 are not very extensive. The CRT and SCCRT conditions developed very high strengths, and immunity from cracking at Kure Beach was obtained only on specimens stressed to less than 50 per cent of their yield strength. In the salt-spray exposure, specimens cut transverse to the rolling direction were strongly susceptible, whereas those cut longitudinally did not crack. More work is needed on this point. The SCT 850 condition was shown to be more susceptible to cracking than was the CRT 850 condition in the atmospheric exposure tests. Differences were also noted in results on different heats in the CRT 850 condition. Perhaps, the two CRT 850 conditions did not have equal amounts of cold reduction.

New data are given for 17-4 PH in sheet form exposed for almost a year at Kure Beach. No failures occurred on specimens in the H 900 condition (yield strength 180,000 psi) stressed up to 90 per cent of the yield strength. Welded specimens in the H 900 condition failed, and a solution heat treatment following the welding did not completely restore the immunity to stress-corrosion cracking. Specimens aged at 1025 F or higher have not failed. The tests are still in progress, and more data should be forthcoming.

Alloys 12 MoV and Stainless W were reported to be quite susceptible to stress-corrosion cracking, with the latter being slightly superior. Higher tempering temperatures for 12 MoV reduced the susceptibility to cracking, at the same time causing a considerable reduction in the strength of the alloy.

INTRODUCTION

The general features of stress-corrosion cracking were summarized in a recent DMIC report[1]* to provide a background for materials and design engineers and for others involved in the use of high-strength steels. Alloys in many metal systems, both ferrous and nonferrous, are susceptible to stress-corrosion cracking in specific environments. This does not necessarily prevent the use of such metals and alloys but indicates that certain precautions should be taken to avoid failures in service. The successful utilization of any metal is dependent, therefore, on adequate consideration of stress-corrosion properties, as well as of its other properties. This is particularly true for the high-strength steels in aircraft and missile applications.

The factors that influence or contribute to stress-corrosion cracking may arise in any or all of the steps and sequences that the metal encounters in being converted from its original to its final form. Heat treatment, quenching, fabrication, welding and other assembly operations, surface finishing, and other production steps may affect either the metallurgical structure and mechanical properties of the alloy, or result in the development of harmful residual stresses in the finished product. The alloys are exposed to a variety of conditions during these operations, and it is important to consider what their effect will be on the stress-corrosion-cracking properties of the materials. Then there are the conditions prevailing during transportation and storage of the finished aircraft or missiles. Careless handling may result in deformation or surface damage which aggravates stress-corrosion cracking of susceptible materials by introducing additional stresses and providing sites for the start of corrosion. Finally, aircraft and missiles are subjected to a variety of environments in operation. Exposure to cyclic wetting and drying, in humid or salt air locations, and long-time underground storage are examples of possible harmful conditions for susceptible materials.

The increasing use of the high-strength steels in the construction of aircraft and missiles within the past few years resulted in the initiation of several test programs designed to provide data on the stress-corrosion susceptibility of such steels. The steels of interest in the high-strength category may be classified as

(1) Stainless steels
(2) Hot-work die steels
(3) Low-alloy engineering steels.

The first of these may be broken down further to include the martensitic stainless steels, the martensitic and semiaustenitic precipitation hardenable stainless steels, and the cold-rolled austenitic stainless steels. Some data

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*References listed on page 32.

on stress-corrosion cracking have become available as a result of the test programs mentioned above, but not all of this information has been published in the technical journals. Furthermore, differences in materials and in details of the tests make evaluation of scattered data difficult.

The purpose of this report is to present a compilation of data accumulated on the stress-corrosion cracking of high-strength stainless steels in laboratory and atmospheric environments. Also, information concerning heat treatments, mechanical properties, and test procedures is included. It is not always possible to make unqualified, quantitative comparisons where so many factors may influence test results. The data tabulated in this report, therefore, are intended to help in the selection of materials for use in aircraft and missile applications rather than to predict the performance of the materials under service conditions. The data were assembled from tests conducted by the U. S. Steel Corporation, Armco Steel Corporation, Allegheny Ludlum Steel Corporation, and the North American Aviation Corporation at Los Angeles. Some of these tests are still in progress, and additional data from these and other test programs could be included in supplements to this report to bring the information up to date.

EXPERIMENTAL DETAILS

Materials Tested

Twelve stainless steels of four types were investigated:

(1) Martensitic
    USS 12 MoV

(2) Martensitic precipitation hardenable
    17-4 PH
    Stainless W

(3) Semiaustenitic precipitation hardenable
    17-7 PH
    PH 15-7 Mo
    AM 350
    AM 355

(4) Cold-rolled austenitic
    AISI 301
    AISI 201
    AISI 202
    USS Tenelon
    USS 17-5 MnV

Method of Stressing

All of the results recorded in this report were obtained on bent-beam specimens. U. S. Steel and Armco used a rigid stainless steel bar with slots machined in it, spaced for either a 4- or 7-inch span. Specimens cut to some length greater than the span between the slots can be stressed by placing one end in one of the slots and bending into a simple arc just enough to slide the other end in the opposite slot (see Figure 1a). The exact specimen length needed to produce the desired tensile stress in the outer fibers at the middle of the specimen is determined from a relationship between the strain, the specimen length and thickness, and the span between the slots in the specimen holder.

North American Aviation used the same principle, but the fixture consisted of two slotted blocks of an epoxy-glass laminate held in place by a bolt and nut. The desired stress level was obtained on one specimen of each group by adjusting the distance between the end blocks with the bolt and nut. The strain on the bent specimen was determined from strain-gage measurements. Then the deflection of the specimen was measured, and this value was used to reproduce the same bending and stress levels in other specimens of the group. Protective coatings were applied to the fixtures.

In the Allegheny Ludlum tests, the strip specimens were bent over a center support in the test assembly. The specimens were bent by tightening the bolts and nuts at the ends of the jig until the desired strain, measured by a strain gage, was produced at the center of the specimens. Each specimen was insulated from the jig assembly by Teflon tape and washers. This fixture is illustrated in Figure 1b.

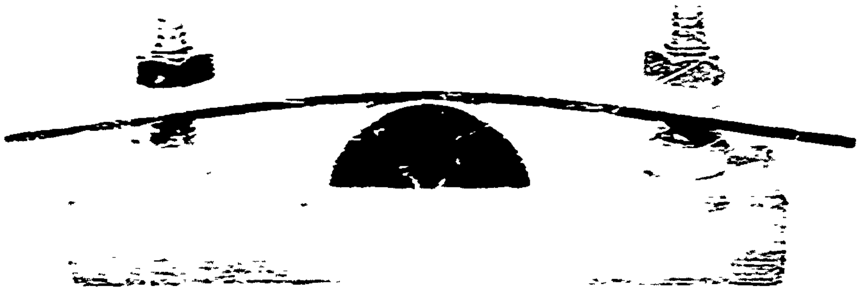
Preparation of Test Specimens

Many factors are known to affect the reproducibility of stress corrosion test results. One of these is the condition of the specimens at the start of the tests. In all of the programs reported, an effort was made to prepare specimens carefully and reproducibly, with a uniform and clean surface, so as to minimize erratic corrosion results caused by variable surface conditions. There were some differences, however, in the actual steps taken to prepare the test specimens. The procedures used are given below.

U. S. Steel

(1) Specimens sheared from sheet stock to proper width, but longer than used in the tests
(2) Heat-treated to get the desired properties
(3) Surfaces ground on 80-grit dry emery belt to remove scale and visible surface defects

a. Fixture used by U. S. Steel, Armco, and, in principle, by North American



b. Three-point loading fixture used by Allegheny Ludlum

FIGURE 1. TEST FIXTURES

(4) Ground on 120-grit emery belt
(5) Cut to length to produce the desired stress after bending
(6) Degreased in trichlorethylene vapor
(7) Washed in distilled water
(8) Rinsed in acetone
(9) Stored in desiccator until put in test.

Armco

(1) Specimens cut from sheet stock
(2) Machined and deburred
(3) Cleaned in inhibited phosphoric acid
(4) Rinsed in distilled water
(5) Heat treated to desired properties
(6) Descaled by wet grit blast to a surface roughness of 25-30 microinches rms.

North American Aviation

(1) Specimens sheared oversize (1-1/2 x 8-1/8 inches)
(2) Alkaline cleaned and coated with a scale-inhibiting compound prior to heat treatment
(3) Heat treated
(4) Machined to 1.000 ±0.001 x 8.000 ±0.001 inches
(5) Liquid honed
(6) Passivated by immersion in 40 per cent nitric acid for 1 hour at room temperature.

Allegheny Ludlum

(1) Specimens sheared from sheet in the desired condition, to a size suitable for mounting in the jigs
(2) Machined to eliminate edge shear effects
(3) Tempering scale removed by pickling in cold dilute nitric-hydrofluoric acid solution.

In the programs where the specimens were bent into the jigs by hand, the specimens were handled with clean canvas gloves to avoid contamination from fingerprints, or other sources. No data are available that permit evaluation of the preparatory systems listed above.

Test Environments

Salt air, marine-atmosphere exposure in the U. S. Steel, Armco, and Allegheny Ludlum programs were conducted at the 80- and 800-foot lots (distance from ocean) at Kure Beach, North Carolina. The North American Aviation specimens were exposed in a 20 per cent salt fog at 95 ± 3 F according to Federal Test Method Standard 151(a), and in a cyclic humidity test, MIL-E-5272 C, to simulate an extreme tropical climate. The details of the latter exposure are given in the tables of test results later in the report. Allegheny Ludlum also exposed specimens in a 20 per cent neutral salt spray. Some specimens in all four programs were exposed to the outdoor atmospheres existing at the company locations, namely, Monroeville and Brackenridge, Pennsylvania, Los Angeles, California, and Middletown, Ohio. The conditions were described as being mild to semiindustrial.

RESULTS

The accumulated data for each class of alloys from all of the sources reviewed has been assembled into tabular form to facilitate comparison and discussion. The data include chemical composition of the alloys, their heat treatment and mechanical properties, exposure conditions, and results. A few blank spaces in the tables indicate that the information was not reported in the original sources. Also, since the tests were conducted by four different companies, there were some scattered data reported that did not fall readily under the table headings. These were included as footnotes to the tables.

Cold-Rolled Austenitic Stainless Steels

The cold-rolled austenitic stainless steels are austenitic at room temperature, and frequently contain small amounts of delta ferrite. Very high strengths may be developed during cold rolling, by a combination of work hardening and transformation of the austenite to martensite. Usually a stress-relieving treatment is used to develop the best combination of strength and ductility. The chemical composition of the steels tested and the treatment and mechanical properties are given in Tables 1 and 2. The results of the stress-corrosion-cracking experiments are in Table 3. The steels attained very high tensile strengths, ranging from about 185,000 psi for full-hard AISI 301, to a range of 245,000 to 289,000 psi for the extra-hard steels. The data in Table 3 indicate that, in general, this class of steels is very resistant to stress-corrosion cracking. It is true that some of the test specimens were lightly stressed (less than 50 per cent of the ultimate tensile strength), but others were stressed at up to 70 per cent of the tensile strength. The tests made by U. S. Steel were at 75 per cent of the yield strength. Only one sample in the entire group developed a crack in the marine-atmosphere exposure. This cracked after 347 days at the 80-foot lot at Kure Beach while stressed at 202,000 psi. Two others developed a crack in the laboratory alternate-immersion test in 3-1/2 per cent salt solution after 39 days. Duplicates did not fail in about 400 days, and it was suggested that the two failures after only 39 days may have been abnormal, caused by a superficial nick or particle of rolled-in scale. If so, it emphasizes the need for care in handling and fabricating these high-strength steels. It may also be noted that the three failures all occurred on specimens cut transverse to the direction of rolling. There is no apparent evidence to indicate whether this is significant.

TABLE 1. CHEMICAL COMPOSITION OF THE COLD-ROLLED AUSTENITIC STAINLESS STEELS

Alloy	Source of Data[a]	Composition, weight per cent										
		C	Mn	P	S	Si	Cr	Ni	Mo	V	N	Cu
AISI 301	USS	0.09	1.24	[illegible]	0.018	0.50	7.36	[illegible]	--	--	--	--
AISI 301[b]	AL	0.11	0.58	0.022	0.016	0.22	17.59	6.91	0.10	--	--	0.25
AISI 201	USS	0.10	7.73	0.029	0.021	0.32	16.53	4.60	--	--	0.15	--
USS Tenelon	USS	0.095	15.10	0.022	[illegible]	0.50	17.95	0.43	--	--	0.46	--
USS 17-5 MnV	USS	0.11	15.5	[illegible]	0.012	0.73	16.19	4.61	2.0	0.32	0.35	--
AISI 2xx	USS	0.12	7.54	0.043	[illegible]	0.46	17.3	4.52	--	--	0.16	--

(a) USS – U.S. Steel Corporation
AL – Allegheny Ludlum Steel Corporation.
(b) Average of two heats.

The other alloys in this group were in the U. S. Steel tests and had been treated to produce yield strengths ranging from 215,000 psi to 264,000 psi. When stressed at 75 per cent of their yield strength, no failures occurred during 240 days' exposure at Kure Beach.

Semiaustenitic Precipitation-Hardenable Stainless Steels

The semiaustenitic precipitation-hardenable stainless steels apparently have received more attention than the others covered in this report, and more data on stress-corrosion-cracking data are available. The physical metallurgy of these alloys has been well summarized in DMIC Report 111.[2] As discussed in that report, the alloys have achieved popularity, because they can be fabricated easily in the annealed condition, and then hardened to high strength levels by a series of thermal treatments. The hardening mechanism consists of transformation from an austenitic to a martensitic matrix,

TABLE 2. MECHANICAL PROPERTIES OF THE COLD-

Alloy	Source of Data(a)	Condition	Reduction by Cold Rolling, per cent	Stress Temperature, F
AISI 301	USS	Extra hard, stress relieved	50	900
AISI 301	AL	Full hard	--	--
AISI 301	AL	Full hard	--	--
AISI 301	AL	Full hard, stress relieved	--	800
AISI 301	AL	Full hard, stress relieved	--	500
AISI 301	AL	Extra hard, stress relieved	--	750
AISI 301	AL	Extra hard, stress relieved	--	750
AISI 301	USS	Extra hard, stress relieved	60	500
AISI 302	USS	Extra hard, stress relieved	60	500
USS TENELON	USS	Extra hard, stress relieved	50	500
USS 17-5 MnV	USS	Extra hard, stress relieved	50	500
USS 17-5 MnV	USS	Extra hard, stress relieved	50	900
USS 17-5 MnV	USS	Extra hard, stress relieved	50	1100
USS 17-5 MnV	USS	Full hard, stress relieved	40	900
USS 17-5 MnV	USS	Full hard, stress relieved	40	1100

(a) USS – U.S. Steel Corporation
AL – Allegheny Ludlum Steel Corporation.
(b) Specimen broke outside of gage marks.

ROLLED AUSTENITIC STAINLESS STEELS

Relief Time, hours	Yield Strength, 1000 psi	Tensile Strength, 1000 psi	Elongation in 2 Inches, per cent	Direction
2	233	249	3.0	Longitudinal
--	154	182	19.0	Longitudinal
--	141	183	17.5	Transverse
--	157	184	7.0	Longitudinal
--	153	167	11.0	Transverse
--	252	259	1.0[b]	Longitudinal
--	271	279	1.0[b]	Transverse
2	229	253	1.2	Longitudinal
2	215	245	2.5	Longitudinal
2	239	254	3.5	Longitudinal
2	251	269	--	Longitudinal
2	260	277	1.5	Longitudinal
2	254	279	4.0	Longitudinal
2	235	256	--	Longitudinal
2	[illegible]	[illegible]	7.0	Longitudinal

TABLE 3. RESULTS OF STRESS-CORROSION CRACKING TESTS

Alloy	Source of Data[a]	Condition[b]	Direction	Applied Stress: Per Cent of Tensile Strength	Applied Stress: 1000 PSI
AISI 301	USS	Extra hard, stress relieved	Longitudinal	75[f]	178.5
AISI 301	AL	Full hard	Longitudinal	10 to 70	18.2-127.4
AISI 301	AL	Full hard	Transverse	10 to 70	18.8-131.3
AISI 301	AL	Full hard, stress relieved	Longitudinal	10 to 70	18.4-128.7
AISI 301	AL	Full hard, stress relieved	Transverse	10 to 70	18.7-130.8
AISI 301	AL	Extra hard, stress relieved	Longitudinal	10 to 70	25.9-181.3
AISI 301	AL	Extra hard, stress relieved	Transverse	10 to 70	28.9-202.2
AISI 201	USS	Extra hard, stress relieved	Longitudinal	75[f]	171.8
AISI 202	USS	Extra hard, stress relieved	Longitudinal	75[f]	161.3
USS TENELON	USS	Extra hard, stress relieved	Longitudinal	75[f]	179.3
USS 17-5 MnV	USS	Full hard, stress relieved	Longitudinal	75[f]	177-198

(a) USS – U.S. Steel Corporation
AL – Allegheny Ludlum Steel Corporation.

(b) See Table 2 for details.

(c) 20 per cent neutral salt spray.

(d) 3-1/2 per cent NaCl solution; 10-minute immersion, 50-minute air dry cycle.

(e) Only at 70 per cent of tensile strength, two specimens for each condition.

(f) Per cent of yield strength.

(g) One specimen stressed at 50 per cent of tensile strength cracked after 39 days.

(h) One specimen stressed at 70 per cent of tensile strength cracked after 39 days.

(i) One specimen stressed at 70 per cent of tensile strength cracked after 347 days.

ON COLD-ROLLED AUSTENITIC STAINLESS STEELS

Number of Specimens	Number of Days Exposure Without Failure				
	Kure Beach, 80-Foot Lot	Kure Beach 800-Foot Lot	Salt Spray[c]	Alternate Immersion[d]	Atmosphere Brackenridge, Pa.[e]
6	240	--	--	--	--
8	398	398	419	405	350
8	398	398	415	405[g]	350
8	398	398	414	388	350
8	398	398	417	388[h]	350
8	398	398	285-391	392	350
8	398[i]	398	344	392	350
6	240	--	--	--	--
6	240	--	--	--	--
6	240	--	--	--	--
15	370	--	--	--	--

plus some precipitation hardening during aging treatments. Alloys 17-7 PH and PH 15-7 Mo are hardened in the above manner, but AM 350 and AM 355 are said to harden mainly by the austenite-to-martensite transformation followed by a tempering heat treatment.

The chemical composition of the alloys in this group are given in Table 4, and the details of the heat treatments are in Table 5. The hardening sequence is seen to include an austenite-conditioning step, during which chromium carbides are precipitated from the austenite. This results in raising the M_s temperature sufficiently that transformation to martensite is more readily accomplished in the subsequent operations. The final treatment is the aging step, during which hardening phases are precipitated in the alloy. The temperature and duration of the aging treatment will have some effect on the size and distribution of the precipitate particles. All of these steps combine to develop the mechanical properties of the heat-treated alloy. The mechanisms of hardening are discussed in much greater detail in the report mentioned above.(2)

TABLE 4. CHEMICAL COMPOSITION OF THE SEMIAUSTENITIC PRECIPITATION-HARDENABLE STAINLESS STEELS

Alloy	Source of Data(a)	Composition, weight per cent											
		C	Mn	P	S	Si	Cr	Ni	Mo	V	Ti	N	Al
17-7 PH	USS	0.075	0.65	--	0.009	0.35	16.83	7.17	--	--	0.077	--	1.[illegible]
17-7 PH	NAA	0.068	0.59	--	--	0.27	15.97	7.26	--	--	--	--	1.16
17-7 PH	Armco(b)	--	--	--	--	--	--	--	--	--	--	--	
PH 15-7Mo	USS	0.072	0.58	--	--	0.32	14.79	6.34	2.47	--	0.053	--	1.13
PH 15-7Mo	NAA	0.070	0.66	--	--	0.24	14.33	7.27	2.34	--	--	--	1.22
PH 15-7Mo	Armco(b)	--	--	--	--	--	--	--	--	--	--	--	
AM 350	NAA	0.12	0.97	--	--	0.35	16.[illegible]	4.24	2.76	--	--	0.09	--
AM 355	NAA	0.14	0.72	--	--	0.29	15.41	4.51	2.71	--	--	0.11	--
AM 355	AL(c)	0.14	0.84	0.023	0.012	0.35	15.29	4.57	2.76	--	--	0.11	--

(a) USS – U.S. Steel Corporation
NAA – North American Aviation, Inc.
AL – Allegheny Ludlum Steel Corporation
Armco – Armco Steel Corporation.
(b) Analysis not reported.
(c) Average of 4 heats.

Cold rolling is also used to produce hardening in the alloys of this group. This causes the austenite to transform to martensite, and the alloy is then aged or tempered to develop the final properties. Alloys in the CH 900 and SCCRT conditions have very high tensile and yield strengths, but it should be noted that their ductility is low. The properties of all of the alloys tested in the group are listed in Table 6.

TABLE 5. HEAT TREATMENT OF THE SEMIAUSTENITIC PRECIPITATION-HARDENABLE STAINLESS STEELS

			Austenite Conditioning			Age or Temper	
Alloy	Condition	Source of Data[(a)]	Temperature, F	Time, minutes	Transformation	Temperature, F	Time, hours
17-7 PH	TH 1050	USS	1400	90	Cool to 60 F within 1 hr, hold 30 min	1050	1-1/2
	TH 950	USS	1400	90	Cool to 60 F within 1 hr, hold 30 min	950	1-1/2
	RH 950	USS	1750	10	Hold 8 hr at -100 F	950	1
	TH 1075	NAA	1400	90	Cool to 32-60 F within 1 hr, hold 30 min	1075	1-1/2
	TH 1050	Armco	1400	90	Cool to 60 F within 1 hr, hold 30 min	1050	1-1/2
	RH 950	Armco	1750	10	Hold 8 hr at -100 F	950	1
	CH 900	Armco	--	--	Cold rolled at mill	900	1
PH 15-7 Mo	TH 1050	USS	1400	90	Cool to 60 F within 1 hr, hold 30 min	1050	1-1/2
	RH 950	USS	1750	10	Hold 8 hr at -100 F	950	1
	RH 950	NAA	1750	20	Hold 5 hr at -110 F	950	1
	BCHT[(b)]	NAA	1625	20	Cool to 1000 F in 45 min, air cool to room temp., 5 hr at -100 F	900	8
	TH 1050	Armco	1400	90	Cool to 60 F within 1 hr, hold 30 min	1050	1-1/2
	RH 950	Armco	1750	10	Hold 8 hr at -100 F	950	1
	CH 900	Armco	--	--	Cold rolled at mill	900	1
	BCHT[(b)]	Armco	1675	20	Cool to 1000 F in 45 min, cool to room temp, 8 hr at -100 F	900	24
AM 350	SCT 850	NAA	1710	20	3 hr at -110 F	850	3
	BCHT[(b)]	NAA	1675	20	Cool to 1000 F in 45 min, cool to room temp, 8 hr at -100 F	900	24
AM 355	SCT 850	NAA	1710	20	3 hr at -110 F	850	3
	BCHT[(b)]	NAA	1675	20	Cool to 1000 F in 45 min, cool to room temp, 8 hr at -100 F	900	24
	CRT 850	AL	--	--	Cold rolled	850	--
	SCCRT 850	AL	--	--	Subzero cooled, cold rolled	850	--

(a) USS - United States Steel Corporation
NAA - North American Aviation, Inc.
Armco - Armco Steel Corporation,
AL - Allegheny Ludlum Steel Corporation

(b) BCHT - braze cycle heat treatment.

TABLE 6. MECHANICAL PROPERTIES OF THE SEMIAUSTENITIC PRECIPITATION-HARDENABLE STAINLESS STEELS

Alloy	Source of Data[a]	Condition	Yield Strength, 1000 psi	Tensile Strength, 1000 psi	Elongation, 2 inches, per cent	Direction
17-7 PH	USS	TH 1050	154	192	8.7	Longitudinal
	USS	TH 950	201	219	3.8	Longitudinal
	USS	RH 950	225	[illegible]	6.7	Longitudinal
	NAA	TH 1075	159	177	11.0	Longitudinal
	Armco	TH 1050[b]	200	214	8.9	Transverse
	Armco	TH 1050[b]	179	191	9.0	Transverse
	Armco	RH 950[b]	217[c]	234	5.0	Transverse
	Armco	CH 900[b]	270	279	6.2	Transverse
PH 15-7 Mo	USS	TH 1050	185	193	2.5	Longitudinal
	USS	RH 950	202	229	5.0	Longitudinal
	NAA	RH 950	223	250	9.0	Longitudinal
	NAA	SCHT	220	241	7.0	Longitudinal
	Armco	TH 1050[b]	207[c]	216	6.5	Transverse
	Armco	RH 950[b]	222[c]	246	4.4	Transverse
	Armco	CH 900[b]	252	252	1.6	Transverse
	Armco	TH 1050[d]	209	218	6.2	Transverse
	Armco	RH 950[d]	219	242	6.2	Transverse
	Armco	RH 1050[d]	217	225	5.5	Transverse
	Armco	SCHT[d]	235	252	4.9	Transverse
AM 350	NAA	SCT-850	175	212	10.5	Longitudinal
	NAA	SCHT	159	205	10	Longitudinal
AM 355	NAA	SCT 850	182	225	9	Longitudinal
	NAA	SCHT	166	195	7.5	Longitudinal
	AL[e]	CRT 850	234	[illegible]	11.5	Longitudinal
	AL[f]	CRT 850	156	219	[illegible]	Longitudinal
	AL	SCCRT 850	304	304	6.5[g]	Longitudinal
	AL	SCCRT 850	253	253	--[g]	Transverse

(a) USS - U.S. Steel Corporation
NAA - North American Aviation, Inc.
Armco - Armco Steel Corporation
AL - Allegheny Ludlum Steel Corporation.
(b) Data for specimens exposed up to June 15, 1958, at 50 and 75 per cent of yield strength.
(c) Average of two heats.
(d) Data for specimens exposed up to June 15, 1958 to July 6, 1959, at 40 and 60 per cent of yield strength. Average of two or three heats.
(e) Heat 35536.
(f) Heat 35808.
(g) Specimen broke outside of gage marks.

Stress-Corrosion Results for 17-7 PH

All of the stress-corrosion data that have been reviewed for Alloy 17-7 PH are tabulated in Table 7. Exposures at Kure Beach, in a 20 per cent salt spray, to a cyclic humidity cycle, and to semiindustrial environments at several localities were evaluated. No failures were reported for exposure periods of 350 to 730 days at any of the three semiindustrial locations included in the tests. The applied stresses ranged from 63,000 psi to 243,000 psi. The environments were described as mild to semiindustrial. No failures were reported in a few tests in the 20 per cent salt spray or in a cyclic-humidity environment. The applied stress levels in these tests varied from 63,000 psi to 126,000 psi.

Exposure to a marine atmosphere at Kure Beach, however, did cause some specimens to crack. The four alloy treatments included in the tests were TH 1050, TH 950, RH 950 and CH 900. It is interesting to note that the CH 900 specimens stressed to 143,000 and 214,000 psi did not fail in 746 days' exposure to the marine atmosphere. These were the strongest alloys tested but also the least ductile. The resistance of 17-7 PH to stress-corrosion cracking when in the CH 900 condition is probably related to the fact that transformation of austenite to martensite is induced by cold work rather than by a heat treatment. In the latter case, precipitation of carbides at grain boundaries may result in the development of corrosion-susceptible paths that favor stress-corrosion cracking.

Examination of the data for the alloy shows how difficult it is to make quantitative evaluations of susceptibility to stress-corrosion cracking. In the TH 1050 condition, for example, 7 out of 27 specimens stressed to 116,000 psi (75 per cent of the yield strength) cracked in an average time of 21 days whereas the other 20 did not fail in 320 days' exposure at the 80-foot lot at Kure Beach. In a test at the 800-foot lot, 2 out of 5 specimens stressed to 151,000 psi failed in an average time of 100 days, while the unfailed specimens were exposed for a total time of 746 days. No explanation has been offered for the wide spread in exposure periods between the specimens that cracked and those that did not crack. In a second heat of the Armco steel in the TH 1050 condition, but having a lower yield strength, no failures were reported for 746 days on specimens stressed to 134,000 psi.

In the RH 950 condition most of the specimens stressed at 90, 75, and 50 per cent of the yield strength (183,000 to 102,000 psi) failed on exposure at Kure Beach. The exposure periods to failure ranged from 2 to 116 days, depending on the stress level and conditions of exposure. Here again, the specimens that did not fail withstood exposures of 380 days at the 80-foot lot and 746 days at the 800-foot lot. In the RH 950 condition the alloy is

TABLE 7. RESULTS OF STRESS-CORROSION-CRACKING TESTS ON ALLOY 17-7 PH

Alloy and Condition	Source of Data(a)	Applied Stress: Per Cent of Yield Stress	Applied Stress: 1000 PSI	Number of Specimens: Exposed	Number of Specimens: Failed	Average Time to Failure, days	Exposure Time of Unfailed Specimens, days	Direction
				Exposed at Kure Beach(b)				
17-7 PH, TH 1050	USS	75	116	27	7	21	320	Longitudinal
	Armco(c)	75	151	5	2	100	746	Transverse
	Armco(c)	75	134	5	0	--	746	Transverse
	Armco(c)	50	101	5	0	--	746	Transverse
	Armco(c)	50	89	5	0	--	746	Transverse
17-7 PH, TH 950	USS	90	181	--	--	1(d)	--	Longitudinal
	USS	75	151	4	4	1	--	Longitudinal
	USS	50	101	--	--	5(d)	--	Longitudinal
17-7 PH, RH 950	USS	90	183	--	--	2(d)	--	Longitudinal
	USS	75	152	30	21	5	320	Longitudinal
	USS	50	102	--	--	15(d)	--	Longitudinal
	Armco(c)	75	168	5	5	7.4	--	Transverse
	Armco(c)	75	165	5	5	51.6	--	Transverse
	Armco(c)	50	112	5	5	[illegible]	--	Transverse
	Armco(c)	50	110	5	1	116.	746	Transverse
17-7 PH, CH 900	Armco(c)	75	214	5	0	--	746	Transverse
	Armco(c)	50	142	5	0	--	746	Transverse
				Exposed to Salt Spray - 20 Per Cent NaCl at 95 ± 3 F				
17-7 PH, TH 1075	NAA	90	126	3	0	--	42	Longitudinal
	NAA	40	63	3	0	--	42	Longitudinal
				Cyclic Humidity Exposure at Relative Humidity of 90 Per Cent or Higher; Heat from 80 - 100 F to 160 F in [illegible] hours; Hold at 160 F, 6 hours; Cool to 80 - 100 F in 16 hours				
17-7 PH, TH 1075	NAA	80	125	3	0	--	51	Longitudinal
	NAA	60	95	3	0	--	51	Longitudinal
	NAA	40	63	3	0	--	51	Longitudinal
				Atmospheric Exposure				
17-7 PH, TH 1050	USS(e)	75	115	7	0	--	500	Longitudinal
	Armco(f)	90	180	--	0	--	730	Transverse
17-7 PH TH 1075	NAA(g)	80	125	3	0	--	350(h)	Longitudinal
	NAA(g)	60	95	3	0	--	350(h)	Longitudinal
	NAA(g)	40	63	3	0	--	350(h)	Longitudinal
17-7 PH, RH 950	USS	75	152	7	0	--	520	Longitudinal
	Armco	90	196	--	0	--	730	Transverse
17-7 PH, CH 900	Armco	90	243	--	0	--	730	Transverse

Footnotes appear on the following page.

Footnotes for Table 7

(a) USS – U.S. Steel Corporation
Armco – Armco Steel Corporation
NAA – North American Aviation, Inc.
(b) U. S. Steel tests, 50-foot lot;
Armco tests, 500-foot lot.
(c) Specimens exposed in test up to June 15, 1953.
(d) Average of three specimens or more.
(e) Atmospheric exposure at Monroeville, Pennsylvania.
(f) Atmospheric exposure at Middletown, Ohio.
(g) Atmospheric exposure at Los Angeles, California.
(h) Specimens still in test.

somewhat stronger and less ductile than in the TH 1050 condition, and consequently it is also more susceptible to stress-corrosion cracking. It should be noted that the data in Table 7 does not permit direct comparison of results in every case because of some spread in the mechanical properties of different heats of the same alloy, and because some specimens were cut in the direction of rolling and others in the transverse direction. Also, the difference in the severity of the environment at the two Kure Beach lots should be considered in comparing the results reported.

A few tests were made with specimens in the TH ·0 condition. Failures occurred within a few days, even on the specimens stressed to 101,000 psi (50 per cent of the yield strength).

Summarizing, 17-7 PH alloy in the highest strength conditions and high applied stresses was shown to be susceptible to stress-corrosion cracking in a marine atmosphere. The susceptibility is not solely related to the strength of the alloy but is also determined by the heat-treatment procedure used to obtain the properties. Some specimens were reported to have been cut parallel to the rolling direction and others transverse, but no direct comparisons of the effect of this variable were made.

Stress-Corrosion Results for PH 15-7 Mo

It was noted earlier in the report that the cold-working and heat-treating conditions for PH 15-7 Mo were the same as those for 17-7 PH. These are given in Table 5. and the mechanical properties of the heats tested in corrosion are in Table 6. Table 8 is a tabulation of the accumulated data on stress-corrosion cracking for PH 15-7 Mo treated by the common procedures and by simulated brazing heat-treatment cycles. Specimens were exposed to semiindustrial atmospheres. at the 80- and 800-foot lots at Kure Beach, in a 20 per cent salt spray, and in a cyclic humidity atmosphere. These were essentially duplicates of the tests on 17-7 PH just described. However, some newer work by Armco and North American Aviation is included.

The results show that the alloy in the TH 1050 is quite susceptible to stress-corrosion cracking in the environment of the 80-foot lot at Kure Beach. A large percentage of the specimens stressed to 60 and 75 per cent of their yield strength were reported cracked after relatively short exposure periods. No failures occurred in 466 days on the specimens stressed to only 40 per cent of the yield strength. Just as with 17-7 PH, however, there was a wide spread in exposure times between those specimens that did fail.

TABLE 5. RESULTS OF STRESS-CORROSION-CRACKING TESTS ON ALLOY PH 15-7 Mo

Alloy and Condition	Source of Data(a)	Applied Stress, Per Cent of Yield Strength	Applied Stress, 1000 PSI	Number of Specimens, Exposed	Number of Specimens, Failed	Average Time to Failure, days	Exposure Time of Unfailed Specimens, days	Direction
				Exposed at Kure Beach, 80-Foot Lot				
PH 15-7 Mo, TH 1050	USS	[illegible]	140	12	9	16	240	Longitudinal
	Armco	60	127	5	3	182	--	Transverse
	Armco	60	125	5	4	72	466	Transverse
	Armco	60	124	5	2	71	466	Transverse
	Armco	40	85	5	0	--	466	Transverse
	Armco	40	84	5	0	--	466	Transverse
	Armco	40	82	5	0	--	466	Transverse
PH 15-7 Mo, RH 950	USS	90	182	--(b)	-	12	--	Longitudinal
	USS	75	152	12	12	15	--	Longitudinal
	USS	50	101	--(b)	9	--	175	Longitudinal
	Armco	60	131	5	5	23.2	--	Transverse
	Armco	60	132	5	5	22.2	--	Transverse
	Armco	60	131	5	5	19	--	Transverse
	Armco	40	87	5	4	172	466	Transverse
	Armco	40	88	5	4	74	466	Transverse
	Armco	40	87	5	1	82	466	Transverse
PH 15-7 Mo, RH 1050	Armco	60	131	5	4	140	466	Transverse
	Armco	60	129	5	4	339	466	Transverse
	Armco	40	83	5	0	--	466	Transverse
	Armco	40	86	5	0	--	466	Transverse
PH 15-7 Mo, SCHT(c)	Armco	60	140	5	5	24.2	--	Transverse
	Armco	60	140	5	5	44.2	--	Transverse
	Armco	40	93	5	5	49.6	--	Transverse
	Armco	40	94	5	5	61.6	--	Transverse
				Exposed at Kure Beach, 800-Foot Lot				
PH 15-7 Mo, TH 1050	Armco	75	161	5	3	164	746	Transverse
	Armco	75	164	5	5	39.8	--	Transverse
	Armco	60	127	5	0	--	466	Transverse
	Armco	60	125	5	0	--	466	Transverse
	Armco	50	124	5	0	--	466	Transverse
	Armco	50	107	5	0	--	746	Transverse
	Armco	50	109	5	0	--	746	Transverse
	Armco	40	85	5	0	--	466	Transverse
	Armco	40	84	5	0	--	466	Transverse
	Armco	40	82	5	0	--	466	Transverse
PH 15-7 Mo, RH 950	Armco	75	174	5	5	63.8	--	Transverse
	Armco	75	175	5	5	14.2	--	Transverse
	Armco	60	131	5	4	179	466	Transverse
	Armco	60	132	5	4	126	466	Transverse
	Armco	60	131	5	4	164	466	Transverse
	Armco	50	116	5	5	169.4	--	Transverse
	Armco	50	117	5	5	82.8	--	Transverse
	Armco	40	87	5	1	346	466	Transverse
	Armco	40	88	5	0	--	466	Transverse
	Armco	40	87	5	0	--	466	Transverse

TABLE 8. (Continued)

Alloy and Condition	Source of Data(a)	Applied Stress: Per Cent of Yield Strength	Applied Stress: 1000 PSI	Number of Specimens: Exposed	Number of Specimens: Failed	Average Time to Failure, days	Exposure Time of Unfailed Specimens, days	Direction
		Exposed at Kure Beach, 800-Foot Lot (Continued)						
PH 15-7 Mo, RH 1050	Armco	60	131	5	0	--	466	Transverse
	Armco	60	129	5	0	--	466	Transverse
	Armco	40	88	5	0	--	466	Transverse
PH 15-7 Mo, BCHT(c)	Armco	60	140	5	5	236.2	--	Transverse
	Armco	60	140	5	5	101.4	--	Transverse
	Armco	40	93	5	0	--	466	Transverse
	Armco	40	94	5	3	333	466	Transverse
PH 15-7 Mo, CH 900	Armco	75	196	5	0	--	746	Transverse
	Armco	50	131	5	0	--	746	Transverse
		Exposed to Salt Spray - 20 Per Cent NaCl at 95 ± 3 F						
PH 15-7 Mo, RH 950	NAA	80	178	2	0	--	42	Longitudinal
	NAA	40	89	3	0	--	42	Longitudinal
PH 15-7 Mo BCHT(d)	NAA	80	176	2	2	7	--	Longitudinal
	NAA	40	88	3	0	--	42	Longitudinal
PH 15-7 Mo, brazed(e)	NAA	40	--	-	0	--	21	--
PH 15-7 Mo, BCHT(f)	NAA	40	--	-	0	--	21	--
		Cyclic Humidity Exposure at Relative Humidity of 95 Per Cent or Higher Heat from 80-100 F to 160 F in 2 hours Hold at 160 F 6 hours Cool to 80-100 F in 16 hours.						
PH 15-7 Mo, RH 950	NAA	80	178	3	0	--	51	Longitudinal
	NAA	60	134	3	0	--	51	Longitudinal
	NAA	40	89	3	0	--	51	Longitudinal
PH 15-7 Mo, BCHT(d)	NAA	80	176	3	1(g)	52	52(h)	Longitudinal
	NAA	40	88	3	0	--	51	Longitudinal
		Atmospheric Exposure						
PH 15-7 Mo, TH 1050	Armco(i)	90	186	-	0	--	730	Transverse
PH 15-7 Mo, RH 950	Armco(i)	90	198	-	0	--	730	Transverse
	NAA(j)	80	178	3	0	--	350(k)	Longitudinal
	NAA(j)	60	134	3	0	--	350(k)	Longitudinal
	NAA(j)	40	89	3	0	--	350(k)	Longitudinal
PH 15-7 Mo CH 900	Armco(i)	75	196	5	0	--	746	Transverse
	Armco(i)	50	131	5	0	--	746	Transverse
PH 15-7 Mo, BCHT(d)	NAA(j)	80	176	3	1(g)	100	350(k)	Longitudinal
	NAA(j)	40	88	3	0	--	350(k)	Longitudinal
PH 15-7 Mo brazed	NAA(j)	40	--	-	0	--	290(k)	Longitudinal
PH 15-7 Mo BCHT(f)	NAA(j)	40	--	-	0	--	290(k)	Longitudinal

Footnotes appear on the following page.

Footnotes for Table 8.

(a) USS – United States Steel Corporation
    Armco – Armco Steel Corporation
    NAA – North American Aviation, Inc.
(b) Average of three specimens or more.
(c) See Armco SCHT, Table 5.
(d) See NAA SCHT, Table 5.
(e) 3/4 x 1-inch patch brazed to center of 1 x 8-inch specimens.
    Brazing alloys: (1) LTCM (80-20) and (2) TS9 alloy.
(f) Brazing cycle:
    1750 F 20 minutes, slow cool to 1040 F (45 minutes), air cool to room temperature
    -50 ± 15 F - 3 hours
    1075 F - 1 hour.
(g) Specimens not properly descaled after heat treatment.
(h) Cracked, but not fractured.
(i) Atmospheric exposure at Middletown, Ohio.
(j) Atmospheric exposure at Los Angeles, California.
(k) Specimens still in test.

and those that did not fail. In the groups that included failed specimens, 20 of 27 specimens failed after exposure periods of 16 to 182 days. Of the unfailed specimens, three were exposed for 240 days and four for 406 days. The data in Table 8 show that different heats treated to the same strength level, and exposed at equal stresses, show a wide variation in average times to failure, 71 to 182 days in one instance. Evidently, the induction period, during which corrosion and crack formation take place, varies considerably between replicate specimens within a heat and also between similar heats.

At the 800-foot lot at Kure Beach, no failures were reported on PH 15-7 Mo specimens exposed for a total of 466 days. This included 15 specimens stressed at 60 per cent of the yield strength (applied stress about 125,000 psi). Duplicates exposed at the 80-foot lot had shown numerous cracking failures, which is a measure of the difference in corrosiveness of the two exposure environments. In an earlier test, 8 of 10 specimens of PH 15-7 Mo, TH 1050 stressed to 75 per cent of the yield strength were cracked after exposure at the 800-foot lot. Here again the average time to failure ranged from 40 to 103 days, and the unfailed specimens withstood 746 days' exposure.

PH 15-7 Mo in the RH 950 condition appears to be quite susceptible to stress-corrosion cracking in the marine environment at the 80-foot lot at Kure Beach. Many of the specimens in this condition failed during the course of the tests, at all stress levels. Average time to failure ranged from 12 days for the most highly stressed group of specimens to 173 days at lower stresses. The most resistant specimens were those tested at 40 per cent of the yield strength (applied stress of about 87,000 psi). Even under these conditions, most of the specimens cracked. On the other hand, the group stressed at 50 per cent of the yield strength (101,000 psi) showed no failures during 175 days' exposure. Perhaps this is an indication of a directional effect since the specimens in this group were taken in the direction of rolling.

Some specimens of PH 15-7 Mo, RH 950 failed at the 800-foot lot at Kure Beach. One specimen stressed at 87,000 psi (40 per cent of yield strength) failed after 346 days' exposure, while at higher stress levels failures occurred in shorter periods. These results indicate that any exposure of this alloy in the RH 950 condition to marine atmospheres should be at relatively low stress levels.

Specimens in the RH 950 condition at stress levels from 89,000 psi to 178,000 psi were also exposed to a 20 per cent salt-spray solution for 42 days and in the cyclic humidity environment for 51 days without failure. As discussed above, large percentages of similarly stressed specimens failed in a sea-coast environment. At similar stress levels, failures at the 80-foot lot occurred generally in shorter periods than the 42 and 51 days listed for the salt-spray and humidity cycles. This might indicate that the Kure Beach environment is more harmful, but perhaps other factors also play a part in the results.

A few tests were made on PH 15-7 Mo in the RH 1050 condition. Specimens in this condition were more resistant than in the RH 950 conditions at both the 80- and 800-foot lots. At the latter site, none of the RH 1050 specimens failed in 466 days' exposure. At the 80-foot lot, the RH 1050 condition showed somewhat better resistance than the TH 1050 condition. This might be expected on the basis that the RH 1050 structure would have fewer carbides precipitated at the grain boundaries, and somewhat reduced tendency to intergranular attack.

A few specimens of PH 15-7 Mo in the CH 900 condition were exposed at Kure Beach. Very high strength is developed during cold rolling rather than by heat treatment, so carbides are not precipitated at the grain boundaries. No failures occurred on exposure for 746 days at stress levels of 131,000 and 196,000 psi.

The final test treatment was designated as BCHT, i.e., braze-cycle heat treatment. This is intended to simulate the conditions that prevail during brazing of the alloy. The cycles used at Armco and North American Aviation are given in Table 5. The austenite conditioning step at 1625 or 1675 F will cause some carbides to precipitate, probably more than at the standard 1750 F temperature and less than at the 1400 F temperature used to form the T condition. Additional carbide precipitation may occur during the cooling to 1000 F in 45 minutes. However, subzero cooling is required in each case to transform the austenite, and further strength is attained by precipitation hardening. According to Table 6, the Armco treatment using the 1675 F conditioning step and a 24-hour aging at 900 F, resulted in a somewhat stronger, but less ductile, condition than the North American treatment. In the latter, the conditioning temperature was 1625 F, and the aging treatment was conducted at 900 F for 8 hours.

A direct comparison of the effect of these treatments on the susceptibility to stress corrosion was not possible, because the specimens were exposed in different environments. Twenty specimens of twenty with the Armco BCHT treatment, at stress levels of from 93,000 to 140,000 psi, failed after relatively short exposure at the 80-foot lot at Kure Beach. At the 800-foot lot, 13 of 20 specimens failed. Failures also occurred in the salt spray on the North American Aviation BCHT specimens in the highly stressed condition but not at lower stresses (88,000 psi). Here again the total exposure time was only 42 days as compared with 466 days on the specimens exposed at Kure Beach. A comparison with North American Aviation specimens in the RH 950 condition, exposed to the salt spray, indicates that the BCHT treatment results in greater stress-corrosion-cracking susceptibility, but this conclusion is based only on very limited testing. Specimens in the North American BCHT condition were also exposed to the cyclic humidity environment for 51 days. One specimen cracked, but this was attributed to improper cleaning following the heat treatment.

Atmospheric exposure at Middletown, Ohio, for periods up to 2 years, has not resulted in any stress-corrosion cracking failures on PH 15-7 Mo in the TH 1050, RH 950 or CH 900 conditions. Other tests in the Los Angeles atmosphere are still in progress, with no failures reported.

Stress-Corrosion Results for AM 350 and AM 355

These alloys are similar to 17-7 PH and PH 15-7 Mo, both in mechanical and thermal treatments and in strength properties. A discussion of the physical metallurgy of the alloys may be found in DMIC Report 111[2] and in a paper by Lula[4].

The stress-corrosion-cracking properties of AM 355 in the CRT and SCCRT conditions were examined by Allegheny-Ludlum Corporation. The data tabulated in Table 9 were taken from a preliminary report issued in 1959. A few additional data on AM 350 and AM 355 in the SCT condition and also treated by the braze-cycle treatment (BCHT) from North American Aviation tests are included in Table 9.

The chemical composition, heat treatments, and mechanical properties of the alloys are given in Tables 4, 5, and 6, respectively. It will be noted that strengths up to about 300,000 psi were developed by the SCCRT treatment on AM 355. Two different heats of AM 355, CRT were treated to produce markedly different properties. These should be noted because the results of stress-corrosion cracking also were different. The designation "CRT 850" does not distinguish the difference in the two heats.

In the Allegheny Ludlum tests, specimens were stressed at 10, 35, 50 and 70 per cent of the ultimate tensile strengths. A glance at Table 9, shows that no failures occurred in any exposure at the two lower stress levels. At the 80-foot lot at Kure Beach, specimens from the higher-strength heat of AM 355, CRT 850 (tensile strength 238,000 psi) failed at both 50 and 70 per cent of the tensile strength, whereas those from the lower strength heat (tensile strength 2[illegible]0,000 psi) did not fail in 321 days' exposure at any stress level. At the 800 foot-lot, specimens from both heats failed, when stressed to 70 per cent of the tensile strength. No explanation was given to account for the failure of one specimen at the 800-foot lot, whereas duplicates at the more severe 80-foot lot did not fail. Exposure to salt spray also resulted in cracking of specimens from the higher strength heat whereas the lower strength specimens did not fail. At the 70 per cent stress level, one specimen failed in one day, and its duplicate did not fail in 329 days. It was noted that similar experiences at U. S. Steel were attributed to probability effects. Specimens of both heats of AM 355, CRT 850 stressed to 70 per cent the tensile strength and exposed to the atmosphere at Brackenridge had not failed after 181 and 321 days, respectively.

In the SCCRT 850 condition, failures occurred only at the 80-ft lot at Kure Beach, on specimens stressed at 50 and 70 per cent of their tensile strength. Since the alloy in this condition is very strong, the applied stress

TABLE 9. RESULTS OF STRESS-CORROSION-CRACKING TESTS ON ALLOYS AM 350 AND AM 355

Alloy and Condition	Source of Data[a]	Applied Stress: Per Cent of Ultimate Tensile or Yield Strength	Applied Stress: 1000 PSI	Number of Specimens: Exposed	Number of Specimens: Failed	Average Time to Failure, days	Exposure Time of Unfailed Specimens, days	Direction
Exposed at Kure Beach, 80-Foot Lot								
AM 355, CRT 850[b]	AL	10	23.8	2	0	--	63	Longitudinal
	AL	35	83.4	2	0	--	321	Longitudinal
	AL	50	119.1	2	2	66	--	Longitudinal
	AL	70	166.8	2	2	122	--	Longitudinal
AM 355, CRT 850[c]	AL	35	73.4	2	0	--	321	Longitudinal
	AL	50	104.8	2	0	--	321	Longitudinal
	AL	70	146.8	2	0	--	321	Longitudinal
AM 355, SCCRT 850	AL	10	30.4	2	0	--	63	Longitudinal
	AL	35	106.4	2	0	--	451	Longitudinal
	AL	50	152.0	2	1	319	451	Longitudinal
	AL	70	212.8	2	2	21	--	Longitudinal
Exposed at Kure Beach, 800-Foot Lot								
AM 355, CRT 850[b]	AL	10	23.8	2	0	--	63	Longitudinal
	AL	35	83.4	2	0	--	321	Longitudinal
	AL	50	119.1	2	0	--	321	Longitudinal
	AL	70	166.8	2	2	152	--	Longitudinal
AM 355, CRT 850[c]	AL	35	73.4	2	0	--	321	Longitudinal
	AL	50	104.8	2	0	--	321	Longitudinal
	AL	70	146.8	2	1	177	321	Longitudinal
AM 355, SCCRT 850	AL	10	30.4	2	0	--	63	Longitudinal
	AL	35	106.4	2	0	--	451	Longitudinal
	AL	50	152.0	2	0	--	451	Longitudinal
	AL	70	212.8	2	0	--	451	Longitudinal
Exposed to Salt Spray – 20 Per Cent NaCl Solution at 95 ± 3 F								
AM 355, CRT 850[b]	AL	10	23.8	2	0	--	359	Longitudinal
	AL	35	83.4	2	0	--	356	Longitudinal
	AL	50	119.1	2	2	171	--	Longitudinal
	AL	70	166.8	2	1	1	359	Longitudinal
AM 355, CRT 850[c]	AL	35	73.4	2	0	--	344	Longitudinal
	AL	50	104.8	2	0	--	344	Longitudinal
	AL	70	146.8	2	0	--	344	Longitudinal
AM 355, SCCRT 850	AL	10	30.4	2	0	--	351	Longitudinal
	AL	35	106.4	2	0	--	351	Longitudinal
	AL	50	152.0	2	0	--	351	Longitudinal
	AL	70	212.8	2	0	--	351	Longitudinal
	AL	10	29.3	2	1	172	215	Transverse
	AL	35	102.7	2	2	2	--	Transverse
	AL	50	[illegible]	2	2	1	--	Transverse
	AL	70	205.3	2	2	2.5	--	Transverse

TABLE 9. (Continued)

Alloy and Condition	Source of Data[a]	Applied Stress: Per Cent of Ultimate Tensile or Yield* Strength	Applied Stress: 1000 PSI	Number of Specimens: Exposed	Number of Specimens: Failed	Average Time to Failure, days	Exposure Time of Unfailed Specimens, days	Direction
Exposed to Salt Spray - 20 Per Cent NaCl Solution at 95 ± 3 F (Continued)								
AM 355, SCT 850	NAA	40*	75	3	3	1.5	--	Longitudinal
AM 355, SCHT	NAA	50*	130	3	3	1.5	--	Longitudinal
	NAA	40*	66	3	3	13.0	--	Longitudinal
AM 350, SCT 850	NAA	40*	70	3	3	3.5	--	Longitudinal
AM 350, SCHT	NAA	50*	135	3	3	6.5	--	Longitudinal
	NAA	40*	68	3	3	5	--	Longitudinal
Alternate Immersion in 3-1/2 Per Cent NaCl Solution; Cycle: 10-minute immersion, 50-minute air dry								
AM 355, CRT 850(c)	AL	10	23.5	2	0	--	345	Longitudinal
	AL	25	53.4	2	0	--	345	Longitudinal
	AL	50	[illegible]	2	0	--	345	Longitudinal
	AL	70	150.5	2	0	--	350	Longitudinal
AM 355, CRT 850(c)	AL	70	146.3	[illegible]	2	--	344	Longitudinal
AM 355, SCCRT 850	AL	10	30.4	2	[illegible]	--	336	Longitudinal
	AL	25	100.4	2	[illegible]	--	[illegible]	Longitudinal
	AL	50	152.0	2	0	--	336	Longitudinal
	AL	70	[illegible]	2	0	--	336	Longitudinal
Atmospheric Exposure								
AM 355, CRT 850(c)	AL	70	[illegible]	[illegible]	[illegible]	--	151	Longitudinal
	AL	70	146.5	2	0	--	221	Longitudinal
AM 355 SCCRT 850(c)	AL	70	212.5	2	0	--	412	Longitudinal
	AL	70	266.3	2	1	12	151	Transverse
AM 355, SCT 850(c)	NAA	80*	150	3	3	110	--	Longitudinal
	NAA	60*	113	3	3	128	--	Longitudinal
	NAA	40*	75	3	3	133	--	Longitudinal
AM 355, SCHT(c)	NAA	50*	130	3	2	273	--	Longitudinal
	NAA	40*	66	3	1	316	356(f)	Longitudinal
AM 350, SCT 850(c)	NAA	80*	140	3	3	110	--	Longitudinal
	NAA	60*	105	3	3	123	--	Longitudinal
	NAA	40*	70	3	3	155		Longitudinal
AM 350, SCHT(c)	NAA	50*	136	2	3	32-64	--	Longitudinal
	NAA	40*	68	3	3	151	--	Longitudinal

TABLE 9. (Continued)

Alloy and Condition	Source of Data[(a)]	Applied Stress: Per Cent of Ultimate Tensile or Yield* Strength	Applied Stress: 1000 PSI	Number of Specimens: Exposed	Number of Specimens: Failed	Average Time to Failure, days	Exposure Time of Unfailed Specimens, days	Direction
				Cyclic Humidity Exposure at Relative Humidity 95 Per Cent or Higher Heat from 80-100 F to 160 F in 2 hours Hold at 160 F 6 hours Cool to 80-100 F in 16 hours				
AM 355, SCT 850	NAA	80*	150	3	3	12	--	Longitudinal
	NAA	60*	113	3	1	13	52[(g,h)]	Longitudinal
	NAA	40*	75	3	2	26[(g)]	51	Longitudinal
AM 355, BCHT	NAA	80*	150	3	0	52[(h)]	--	Longitudinal
	NAA	40*	66	3	0	52[(h)]	--	Longitudinal
AM 350, SCT 850	NAA	80*	140	3	3	12	--	Longitudinal
	NAA	60*	105	3	3	13.5	--	Longitudinal
	NAA	40*	70	3	1[(g)]	14	51	Longitudinal
AM 350, BCHT	NAA	80*	136	3	3	12	--	Longitudinal
	NAA	40*	68	3	0	--	52[(h)]	Longitudinal

* Indicates percentage of tensile yield strength.

(a) AL – Allegheny Ludlum Steel Corporation
NAA – North American Aviation, Inc.

(b) Heat 35526.

(c) Heat 35806.

(d) Atmospheric exposure at Brackenridge, Pennsylvania.

(e) Atmospheric exposure at Los Angeles, California.

(f) Test still in progress.

(g) Specimens not properly descaled after heat treatment.

(h) Specimens partially fractured.

was over 200,000 psi on some specimens. No failures occurred at the 800-foot lot or in the 20 per cent salt spray. These specimens were all cut longitudinally, i.e., in the direction of rolling. A strong directional effect was revealed in the salt spray. Specimens that were cut transverse to the direction of rolling cracked very quickly, even at an applied stress of about 100,000 psi. This effect was also observed in the atmospheric exposure test.

AM 355 in the SCT 850 condition was evaluated in the North American tests. In this condition, the alloy had a yield strength of about 190,000 psi. The data in Table 9 show that the alloy in this condition is strongly susceptible to stress-corrosion cracking. Failures occurred in all three environments, even at the lower stress levels of 40 per cent of the yield strength (75,000 psi). This is probably related to carbide precipitation during the L-anneal, which conditions the austenite so that complete transformation will occur during subzero cooling. Carbides are precipitated at the grain boundaries, which presumably results in corrosion-susceptible paths. A comparison of the results of atmospheric exposure tests for the CRT 850 and the SCT conditions at comparable stress levels shows that specimens in the SCT condition are susceptible to cracking, whereas those in the CRT 850 condition were not. Exposures were at different locations, but it is probable that transformation by cold rolling (CRT) occurred without the precipitation of carbides at the grain boundaries (as in the SCT condition), and therefore resulted in a structure less susceptible to stress-corrosion cracking.

The braze-cycle heat treatment (BCHT) which includes the slow cooling from 1675 F to 1000 F, resulted in slightly lower properties (yield strength 166,000 psi). The alloy in this condition was also susceptible to cracking. Based on the reported data, the times to failure were slightly longer than for the alloy in the SCT 850 condition. However, they were of the same order of magnitude, and the differences may not be significant.

The North American Aviation program also included tests on AM 350, SCT 850 and AM 350, BCHT. The results were similar to those with AM 355, and the same comments apply.

Martensitic and Martensitic Precipitation-Hardenable Stainless Steels

In these two classes of steels, the austenitic structure is transformed to martensite during cooling to room temperature from the annealing temperature. High strength is developed by subsequent tempering or precipitation-hardening treatments. Three steels, one martensitic, 12 MoV, and two martensitic precipitation hardenable, Stainless W and 17-4 PH, have been tested for susceptibility to stress-corrosion cracking. The chemical compositions of the steels tested are given in Table 10, and the details of the heat treatments and mechanical properties are in Table 11.

TABLE 10. CHEMICAL COMPOSITION OF THE MARTENSITIC AND MARTENSITIC PRECIPITATION-HARDENABLE STAINLESS STEELS

Alloy	Source of Data[a]	C	Mn	P	S	Si	Cr	Ni	Mo	V	Ti	N	Al	Cu	Cb
12 MoV	USS	0.25	0.50	0.019	0.015	0.45	12.15	0.63	0.93	0.33	--	--	--	--	--
Stainless W	USS	0.06	[illegible]	0.015	0.013	[illegible]	16.72	6.66	0.21	--	0.92	0.034	0.24	-	--
17-4 PH	Armco	0.044	0.27	0.022	0.014	0.46	15.91	4.37	--	--	--	--	--	3.42	0.22
17-4 PH[b]	Armco	0.033	[illegible]	0.021	0.011	0.42	16.31	4.93	--	--	--	--	--	3.40	0.19

(a) USS - U. S. Steel Corporation
Armco - Armco Steel Corporation.
(b) Weld wire.

Stress-corrosion data for the 12 MoV and Stainless W grades were taken from the U. S. Steel report[5], and those for 17-4 PH sheet are preliminary data from incomplete tests being conducted by Armco. The results are tabulated in Table 12.

The data in Table 11 show that the heat treatment selected for 12 MoV alloy resulted in high strength. The yield strength was over 205,000 psi, and corrosion tests at Kure Beach (80-foot lot) were carried out at 50 and 75 per cent of the yield strength. 12 MoV alloy, in the condition tested, is strongly susceptible to stress-corrosion cracking. This was also the conclusion from atmospheric-exposure tests at Monroeville, where 45 of 45 specimens (at 75 per cent of the yield strength) failed after an average exposure period of 5 days. Additional work has shown that the alloy was not susceptible to stress-corrosion cracking when tempered at 1100 or 1200 F. Under these conditions, however, the yield strength was reported to be 135,000 psi, considerably lower than that obtained by tempering at 900 F.

Stainless W, was also hardened to a yield-strength level of about 200,000 psi. The hardening mechanism in this case was by precipitation of compounds of titanium and aluminum within the martensitic structure during the aging treatment. Exposure at Kure Beach at 50 to 90 per cent of the yield strength resulted in failures within relatively short periods. During outdoor exposure at Monroeville, however, no failure occurred over a period of 520 days. Thus, at high strength levels, Stainless W appears to be somewhat more resistant than 12 MoV.

The data shown for alloy 17-4 PH are for the material in this sheet form which has not been available heretofore. Specimens were cut from 0.050-inch sheet. The high strength in this alloy is developed during the aging step, which causes precipitation of compounds within the martensite. Aging at 900 F resulted in tensile strengths of slightly over 200,000 psi with

TABLE 11. HEAT TREATMENT AND MECHANICAL PROPERTIES OF THE MARTENSITIC AND MARTENSITIC PRECIPITATION-HARDENABLE STAINLESS STEELS

Alloy	Source of Data[a]	Heat Treatment: Austenitize or Solution Treat, Temperature, F	Heat Treatment: Austenitize or Solution Treat, Time, minutes	Heat Treatment: Tempered or Aged, Temperature, F	Heat Treatment: Tempered or Aged, Time, hours	Yield Strength, 1000 psi	Tensile Strength, 1000 psi	Elongation in 2 Inches, per cent
12 MoV	USS	1850	15	900	4	205	256	10.5
Stainless W	USS	1900	15	1000	0.5	201	202	7.2
17-4 PH	Armco	1900	10	900	1	181.0	202.2	9
	Armco	1900	10	1025	1	155.4	166.8	10
	Armco	1900	10	1075	1	150.8	162.2	9
	Armco	1900	10	1150	1	113.2	139.4	14
17-4 PH, solution treat, weld, and age	Armco	1900	10	900	1	183.0	203.5	4
	Armco	1900	10	1025	1	160.8	175.9	6
	Armco	1900	10	1075	1	150.0	161.2	6.5
	Armco	1900	10	1150	1	115.4	115.4	12
17-4 PH, weld, solution treat, and age	Armco	1900	10	900	1	182.6	206.1	6.5
	Armco	1900	10	1025	1	159.6	166.3	6
	Armco	1900	10	1075	1	153.8	161.1	7
	Armco	1900	10	1150	1	130.4	147.0	7.5

(a) USS - U. S. Steel Corporation
Armco - Armco Steel Corporation.

TABLE 12. RESULTS OF STRESS-CORROSION-CRACKING TESTS ON THE MARTENSITIC AND MARTENSITIC PRECIPITATION-HARDENABLE STAINLESS STEELS

Alloy and Condition	Source of Data(a)	Applied Stress: Per Cent of Yield Strength	Applied Stress: 1000 PSI	Number of Specimens: Exposed	Number of Specimens: Failed	Average Time to Failure, days	Exposure Time of Unfailed Specimens, days
			Exposed at Kure Beach, 80-Foot Lot				
12 MoV	USS	75	153.6	40	40	1	--
	USS	50	102.5	--	--	1.4(b)	--
Stainless W	USS	90	180.9	--	--	22(b)	--
	USS	75	150.8	12	12	47	--
	USS	50	100.5	--	--	65(b)	--
Not Welded							
17-4 PH, H 900	Armco	90	162.9	5	0	--	322
	Armco	75	135.8	5	0	--	322
17-4 PH, H 1025	Armco	90	139.9	5	0	--	322
	Armco	75	116.6	5	0	--	322
17-4 PH, H 1075	Armco	90	135.7	5	0	-	322
	Armco	75	113.1	5	0	--	322
17-4 PH, H 1150	Armco	90	101.9	5	0	--	322
	Armco	75	84.9	5	0	--	322
17-4 PH, H 900	Armco	90	--	5	3	322	560
17-4 PH, H 1150	Armco	90	--	5	0	--	560
Welded, Then Solution Treated and Aged							
17-4 PH, H 900	Armco	90	164.3	5	5	22	--
	Armco	75	137.0	5	4	114	322
17-4 PH, H 1025	Armco	90	143.6	5	0	--	322
	Armco	75	119.7	5	0	--	322
17-4 PH, H 1075	Armco	90	138.4	5	0	--	322
	Armco	75	115.4	5	0	--	322
17-4 PH, H 1150	Armco	90	117.4	5	0	--	322
	Armco	75	97.9	5	0	--	322
Solution Treated, Welded, and Aged							
17-4 PH, H 900	Armco	90	164.7	5	5	20	--
	Armco	75	137.3	5	5	31	--
17-4 PH, H 1025	Armco	90	144.7	5	0	--	322
	Armco	75	120.6	5	0	--	322
17-4 PH, H 1075	Armco	90	135.0	5	0	--	322
	Armco	75	112.5	5	0	--	322

TABLE 12. (Continued)

Alloy and Condition	Source of Data[(a)]	Applied Stress: Per Cent of Yield Strength	Applied Stress: 1000 PSI	Number of Specimens: Exposed	Number of Specimens: Failed	Average Time to Failure, days	Exposure Time of Unfailed Specimens, days
			Exposed at Kure Beach, 80-Foot Lot (Continued)				
Solution Treated, Welded, and Aged (Continued)							
17-4 PH, H 1150	Armco	90	103.9	5	0	--	322
	Armco	75	86.0	5	0	--	322
			Atmospheric Exposure[(c)]				
12 MoV	USS	75	153.8	45	45	5	--
Stainless W	USS	75	150.8	7	0	--	520

(a) USS - U. S. Steel Corporation
Armco - Armco Steel Corporation.
(b) Average of three specimens, or more.
(c) Atmospheric exposure at Monroeville, Pennsylvania.
Data on 17-4 PH are preliminary results from incompleted tests.

a yield strength of about 180,000 psi. Other aging treatments at higher temperatures, up to 1150 F, resulted in correspondingly lower strengths. Stress-corrosion-cracking tests at Kure Beach (80-foot lot) are being made on both ordinary specimens and welded specimens at 90 and 75 per cent of the yield strength. The composition of the weld wire was the same as that of the test material (see Table 10). After welding, one set of specimens was solution treated before aging, to reduce or eliminate nonuniform strains or precipitation in the adjacent metal. It would be expected that this should result in a more uniform response to the subsequent aging treatment. The other group was solution treated, welded, and aged. Heat-treating scale was removed by grinding or wet blasting with alumina grit and Pangbornite. After exposure for 322 days, no failures had occurred in the unwelded specimens at any stress level. In an earlier test, three out of five specimens cracked in 322 days, when stressed at 90 per cent of the yield strength. The other two, and a group stressed at 75 per cent of the yield strength did not fail in 560 days. The welded specimens in the H 900 condition, and not solution treated after welding, failed within a relatively short time. This is an indication that welding is responsible for some change in structure or strain condition, as mentioned above. Solution treatment after welding was beneficial, but it did not prevent failure of the H 900 specimens after a somewhat longer period of exposure. No failures have occurred in the welded specimens aged at 1025, 1075, and 1150 F.

On the basis of these incomplete tests, 17-4 PH sheet material shows good resistance to stress-corrosion cracking in a marine atmosphere. Welding of the alloy in the highest strength condition (H 900) reduced the resistance to cracking. The standard solution heat treatment, following welding, apparently does not completely restore the resistance to stress-corrosion cracking of material. Therefore, in stress-corrosion environments it would appear to be safer to use material aged at higher temperatures, if the lower strength achieved under these conditions is acceptable.

DISCUSSION OF RESULTS

Most of the comments about the results have already been made in the discussion of each class of alloys. From a general standpoint, it is apparent that the need for stress-corrosion-cracking data for the high strength stainless steels has been recognized, and experimental work has been started to provide such information. A reliable evaluation of the susceptibility to stress-corrosion-cracking of a material involves the consideration of many variables, and consequently a large amount of time-consuming experimental work. Therefore, it has been emphasized that most of the experimental programs to evaluate the susceptibility of the high strength stainless steels to stress-corrosion cracking are still in progress, and that the data reported here should be considered preliminary in nature. Furthermore, correlation of these experimental results with actual service performance has not been established as yet. The fact that cracking has occurred under some experimental conditions does not mean that the alloy will crack under all service conditions. It is an indication, however, that such an alloy should be used with due regard to environmental and stress conditions that may exist in the intended service.

Tabulations of the results of tests, such as those included in this report, help to visualize in a general way what has been done, and to point out where additional work may be required.

The results of tests reported to date are given in Tables 3, 7, 8, 9, and 12. These show that the majority of the specimens were exposed to the marine atmosphere at Kure Beach. Laboratory tests included the salt spray, alternate immersion in a salt solution, and a cyclic humidity exposure. Exposure tests in semiindustrial outdoor atmospheres were made at the locations of the companies conducting the tests.

Any number of comparisons of the data could probably be made, but at this stage some of the tests are incomplete, and in other cases there is not enough information available to account for the wide spread observed in times to failure.

It is to be expected that the metallurgical structure developed by thermal treatment or mechanical deformation will affect the results. The CH 900 condition, for example, resulted in the highest strength, but the alloy was immune from stress-corrosion cracking. This may be related to the fact that condition CH 900 does not involve heat treatment in the temperature range at which carbides will precipitate. Therefore, carbides at the grain boundaries would not be expected in alloys in the CH 900 condition.

The results for PH 15-7 Mo are somewhat more consistent than those for 17-7 PH. Here again, the alloy in the CH 900 condition was not susceptible to cracking in the marine exposure. In this alloy also, the RH 950 condition seems to produce a more susceptible structure than TH 1050. Cracking occurred on the RH 950 specimens at applied stresses as low as 87,000 psi, representing only 40 per cent of the yield strength. At similar stresses, the TH 1050 condition did not crack by stress corrosion. It would appear from these results that the extent of stress-corrosion cracking is not determined solely by the presence of carbides at the grain boundaries. Such factors as the quantity of precipitate, its dispersion in the structure, and its composition may be the controlling considerations.

It would be of interest to study the effect of these factors, as well as other microstructural details, such as the amount of retained austenite, the presence of delta ferrite, and perhaps the carbon content of the martensite, on the stress-corrosion-cracking properties of these steels. Of course, other variables that affect results, that is, specimen preparation, stressing, and details of exposure, would have to be controlled and taken into account in such an investigation.

WORK IN PROGRESS

The results of the stress-corrosion-cracking tests on the high-strength stainless steels that have been assembled in this report, represent a good start in the direction of providing such information for design and materials engineers in the aircraft and missile industries. Some useful data have been accumulated. However, some unexplained lack of reproducibility was also evident in several of the tests. While some spread in corrosion test results is expected, enough data must be accumulated to attach proper significance to it. Therefore, some phases of the programs discussed in this report are being continued. Also, several new programs are in their early stages.

It has often been emphasized that many factors may influence stress-corrosion-cracking results. Work is in progress to standardize every phase of the tests required to evaluate semiaustenitic precipitation-hardenable stainless steels. A report has been prepared(5) in which every detail of specimen preparation, heat treatment, stressing, exposure to laboratory-type environments, operating conditions, and reporting of results has been specified. A continuation of this work describes the details of ring-type specimens for testing specimens in the short transverse direction.(6) The work so far in both of the programs mentioned has been concerned with the establishment of standard procedures. Testing will be conducted by numerous participating aircraft companies and by Allegheny Ludlum and Armco Steel Corporations. Salt-spray and alternate-immersion exposure tests are planned for stressed, strip specimens of 17-7 PH, 17-4 PH, PH 15-7 Mo, AM 350, and AM 355. Ring-type specimens for some of these alloys are included. Also, some specimens of AM 355 and 17-4 PH will be exposed to a marine atmosphere. This is a comprehensive program that should produce a large quantity of valuable data.

The difficulties of translating results of accelerated stress-corrosion-cracking tests into expected service results have also been mentioned before. A comprehensive program, sponsored by Frankford Arsenal, has been in progress for about 1 year at Mellon Institute, Pittsburgh, Pennsylvania, and at Aerojet-General Corporation, Azusa, California. High-strength materials, including AM 355 and PH 15-7 Mo, which are of interest in this report, will be tested for susceptibility to stress-corrosion cracking in many environments. The Aerojet-General tests will be in environments that the alloys encounter during fabrication and storage of missiles. The Mellon Institute tests on the same heats of the alloys, will be made in synthetic and artificial environments. The work on these two programs so far has been concerned with procurement of materials, checking of heat-treatment procedures, determination of the mechanical properties of the alloys, preparation of exposure facilities, and evaluation and development of the stressing procedures. Preliminary stress-corrosion tests have been made to check out the various steps. Actual testing of the selected alloys will probably be conducted within the next 12 months and should result in valuable comparisons of the effect of many synthetic and natural environments on stress-corrosion cracking.

Another comprehensive stress-corrosion-cracking program is being conducted by the National Bureau of Standards for the Bureau of Naval Weapons. The precipitation-hardenable stainless steels in several heat-treated conditions are included in the list of alloys being evaluated. Bent beam specimens stressed at 50, 75, 90, and 100 per cent of the yield strength were exposed to the marine atmosphere at Kure Beach a few months ago.

Additional work has also been done on AM 355 and AM 350, but it has not been reported yet. These data, along with the results of the other programs now in progress, should be of great value in the utilization of high-strength stainless steels at the high stress levels desired in modern aircraft and missiles.

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136B	The Effects of Alloying Elements in Titanium, Volume B. Physical and Chemical Properties, Deformation and Transformation Characteristics, May 29, 1961
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141	Titanium-Alloy Forgings, December 19, 1960 (PB 151100 $2.25)
142	Environmental Factors Influencing Metals Applications in Space Vehicles, December 27, 1960 (PB 151101 $1.25)
143	High-Strength-Steel Forgings, January 5, 1961 (PB 151102 $1.75)
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145	Design Information on Titanium Alloys for Aircraft and Missiles, January 10, 1961
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147	The Factors Influencing the Fracture Characteristics of High-Strength Steel, February 6, 1961 (PB 151106 $1.25)
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150	A Review of Bending Methods for Stainless Steel Tubing, March 2, 1961 (PB 151109 $0.50)
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153	Physical Metallurgy of Nickel-Base Superalloys, May 5, 1961 (AD 253041 $1.25)
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